WAL · TR 112/91

# WATERTOWN ARSENAL

## LABORATORIES

CORRELATION OF SELECTED SUBSIZE CHARPY BARS
VERSUS THE STANDARD CHARPY BAR

BY

CHARLES H. CURLL

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O.O. PROJECT: INDUSTRIAL PREPAREDNESS MEASURE,
DEVELOPMENT OF SUBSIZE CHARPY STANDARD
P.E.S.D. NO.: 60304231-15-65003
REPORT NO.: WAL TR 112/91
FILING SUBJECT: SUBSIZE CHARPY

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(6) CORRELATION OF SELECTED SUBSIZE CHARPY BARS
VERSUS THE STANDARD CHARPY BAR

(9) TECHNICAL REPORT

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(10) Charles H. /Curll

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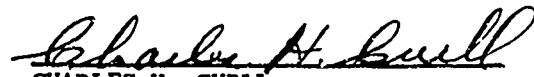370850 alt

WATERTOWN ARSENAL LABORATORIES

TITLE

CORRELATION OF SELECTED SUBSIZE CHARPY BARS
VERSUS THE STANDARD CHARPY BAR

ABSTRACT

To provide a means of impact acceptance testing of specimens which
must be obtained from thin sections, a study was made of the Charpy V notch
impact properties of steels over a range of temperatures encompassing transi-
tions from ductile to brittle behavior in various specimen sizes.

The test data reveal a nonlinear relationship between the energy re-
quired to fracture standard-size and given subsize V notch Charpy specimens
outside the transition temperature range for the steels investigated.  A
more comprehensive investigation on several other steel types is now in
progress.

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# INTRODUCTION

With the advent of thin-wall cylinders for rockets and gun tubes, it has become necessary to provide a means of impact testing materials from such sections for Ordnance acceptance purposes. Because it is not possible to obtain standard-size Charpy impact specimens from thin sections, a correlation between the energies to fracture standard and subsize Charpy V notch impact specimens needs to be established. It is the purpose of this report to develop a correlation between the data from the selected subsize and standard-size Charpy V notch impact specimens.

A literature survey revealed previous investigations on size relationships in the impact test have been made by Dr. Max Moser,[1] Messrs. D. E. McCarthy and J. H. Hollomon,[2] and by Mr. D. C. Buffum.[3] The work in this investigation, however, is unrelated to the work by Dr. Max Moser. The other papers indicate that the transition temperature* decreases with a decrease in specimen size, small changes in the notch radius have negligible effect on the impact data, and the energy data (taken from outside the transition range) are correlatable between the standard and selected subsize Charpy impact specimens.

This report describes the materials used, the experimental work done, and illustrates the graphs developed which relate the impact energies required to fracture standard and subsize Charpy V notch specimens.

## MATERIALS

The following materials were used in this investigation:

### CHEMICAL COMPOSITIONS

| Material | C | Mn | Si | P | S | Ni | Cr | Mo |
|---|---|---|---|---|---|---|---|---|
| Cast Steel | .28 | .61 | .26 | - | - | 2.37 | .86 | .45 |
| AISI-4340 | .37 | .75 | .27 | .013 | .013 | 1.70 | .83 | .25 |
|  | to | to | to | to | to | to | to | to |
|  | .385 | .77 | .28 | .016 | .015 | 1.80 | .86 | .27 |

These materials were heat treated as follows:

### AISI-4340 - Heat-Treat #1

| Austenitize | 1600°F | 2 hrs. | Oil Quench |
| Draw | 1200°F | 2 hrs. | Oil Quench |
| Draw | 570°F | 3 hrs. | Air Cool |

### AISI-4340 - Heat-Treat #2

| Normalize | 1650°F | 2 hrs. | Air Cool |
| Austenitize | 1600°F | 2 hrs. | Oil Quench |
| Draw | 1035°F | 2 hrs. | Oil Quench |
| Draw | 570°F | 3 hrs. | Air Cool |

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*Transition temperature is defined as the lowest temperature at which the specimen breaks with a 100% fibrous fracture.

The cast steel was received as a section of gun tube with a Rockwell "C" hardness of 40 and was used in the as-received condition. The AISI-4340 was received as Charpy impact specimen blanks and was heat-treated as shown above. Heat-treat #1 yielded a Rockwell "C" hardness of 27 and heat-treat #2 yielded a Rockwell "C" hardness of 35. Longitudinal specimens were used for all tests.

The various sizes of specimens tested in this investigation are tabulated in Figure 1. The limiting wall thickness of the standard 57mm recoilless gun tube and a desire to maintain a simple relationship between specimen cross-sectional areas were the factors considered in determining subsize specimen geometries. The notch radii were held at .010"R based upon the findings of D. C. Buffum (see Reference 3). It should be pointed out that subsize specimens of equivalent cross-sectional area, with different geometries than the specimens used in this investigation, will have quite different resultant energy values.

## TEST PROCEDURE

V notched Charpy bars in various sizes, ranging from full size (standard) to one-ninth size (cross-sectional area measurement), were tested over a range of temperatures encompassing their transitions from ductile to brittle behavior. All specimens were broken in the conventional manner on a Sonntag impact testing machine (capacity 240 ft-lb; pendulum velocity 16.8 feet per second). Special anvils and shims were provided to maintain the point of impact at the center of percussion of the pendulum when non-standard specimens were tested. For the shorter-length specimens, the anvil span was shortened to a distance of 0.787" from the normal span of 1.574".

## TEST RESULTS AND DISCUSSION

Tables I, II, and III list testing temperatures, averaged energies absorbed (three tests at each temperature), and percentages of fibrosity in the fracture faces. The energy versus temperature data are presented graphically in Figures 2, 3, and 4.

The energy-temperature curves illustrated in Figures 3 and 4 for the AISI-4340 steels indicate a general lowering of the temperature range in which the transition from high to low energy takes place with decreasing specimen size. This is in agreement with the findings of both Buffum, and McCarthy and Hollomon (see References 2 and 3). The temperature at the onset of crystallinity (maximum temperature showing evidence of cleavage cracking at the fracture faces) is also lowered in a similar manner. These phenomena are in accordance with the generally observed behavior of physical test specimens where the temperatures at which the transitions from ductile to brittle fracture take place are lowered with decreasing specimen size. This effect,

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attributable to the reduced plastic constraint and strain rate* values associated with smaller specimen dimensions, varies the ratio between the energies required to fracture standard and subsize specimens in the transition range; therefore, obtaining any relationship between these energy values that will hold over the entire test temperature range is precluded unless the factors affecting plastic constraint and strain-rate susceptibility are included as variables.

Since these phenomena are not completely understood and, in any case, difficult to determine, no attempt has been made to obtain an energy correlation except at temperatures outside the transition range. This is in agreement with the findings of McCarthy and Hollomon (see Reference 2). The transition temperature curves for the cast steel specimens (Figure 2) do not show well-defined transition zones, and the temperature at the onset of crystallinity is not greatly lowered with decreasing specimen size, as is the case with the AISI-4340 steel. Furthermore, in the cast steel, the energy to fracture is almost directly proportional to the specimen cross-sectional area. This proportionality holds quite closely over practically the entire test temperature range and is apparently due to the highly notch-sensitive characteristics of this material, which allow low-energy fractures to initiate and propagate despite reduced plastic constraint and strain rate values even at room temperatures. Plastic deformation is thereby restricted for the most part to the fracture surface only.

A plot relating the energies required to fracture standard and subsize Charpy specimens (for the steels investigated) at temperatures above the transition range (of the standard-size specimen) is illustrated in Figure 5. A smooth curve, approaching the origin, has been drawn through the plotted points representing the impact energies for all three steels in each specimen size. This nonlinear relationship is not in agreement with the linear relationship developed by McCarthy and Hollomon. It is believed that the lack of data is responsible for the straight-line relationship formerly developed. Although additional data from other steels are required to substantiate these curves, it appears that by their use the standard Charpy impact energy values for any steel may be determined from testing any of the subsize Charpy bar geometries used in this investigation at temperatures. outside the transition range of the standard-size specimen.

In Figure 6 a replot of the curves of Figure 5 is made, and data taken from within the transition range are superimposed upon the curves to illustrate how the relationships between the energies to fracture standard and subsize V notch specimens deviate, in a somewhat irregular manner, from the relationships established at temperatures outside the transition range. Except for data from the cast steel, which lie on the curves regardless of temperature, the plotted points in general fall to the right of the curves, indicating that the energy required to fracture a standard-size Charpy specimen within its transition range is less than that indicated by the

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*From simple geometrical considerations it can be shown that strain rate in testing Charpy specimens is a function of the depth of the specimen below the notch.

energy relationships established for above its transition range (Figure 5).
At temperatures below the transitions where the fractured surfaces of all
specimens approach 100% crystallinity, the variable effects of plastic con-
straint and strain rate are minimized, and the data more closely fit the
curves.

The data from Tables I, II, and III reveal further that, in general,
when the width of specimens of constant depth are varied, the energy
required to fracture is directly proportional to their cross-sectional
areas when the same percentages of fibrosity occur on their fractured sur-
faces. For example, the energy required to fracture the one-quarter size
bar at any particular fibrosity level is half that required for the half-
size bar (of the same depth under the notch) exhibiting the same percentage
of fibrosity on the fractured surfaces. Thus, by selecting an energy value
for the one-quarter size bar at a particular fibrosity level, and multiplying
by the size ratio (two), the energy required to fracture the half-size bar
at the same fibrosity level is derived. Examples of calculated and observed
energies for the half-size bars in the AISI-4340 steel (heat treat #2)
are tabulated below:

### (FROM TABLE III)

| 1/4 Size Bar Energy (ft-lb) | Fibrous Content (%) | Calculated Energy for 1/2 Size Bar (ft-lb) | Observed Energy for 1/2 Size Bar (ft-lb) |
|---|---|---|---|
| 7.9 | 100 | 15.8 | 16.2 |
| 4.8 | 55 | 9.6 | 9.3 |
| 3.1 | 20 | 6.2 | 6.2 |

### CONCLUSIONS

The results of this investigation indicate the following:

1. An empirical correlation has been shown to exist, for the materials
investigated, between the Charpy impact energy values for standard and
selected subsize V notch specimens at temperatures above the transition
range.

2. Within the transition range, variables including plastic constraint
and strain rate susceptibility preclude any correlation that does not in-
clude the factors affecting these variables.

### RECOMMENDATIONS

It is recommended that the results of this investigation be verified
by testing a wide variety of steels in a similar manner.

- 6 -

## REFERENCES

1. MOSER, M., Dr., "A New Method of Interpreting Notched Bar Impact Test Results," *Transactions ASM*, March 1925, Vol. VII, No. 3, p. 297.

2. McCARTHY, D. E. and HOLLOMON, J. H., "Investigation of Subsized Charpy Specimens," WAL Report No. 112/48, 6 August 1945.

3. BUFFUM, D. C., "The Effect of Dimensional Changes on Square V Notched Charpy Bars," WAL Report No. 112/75, 13 January 1949.

## TABLE I

| AVERAGED* IMPACT TEST RESULTS OF CAST STEEL | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | FULL SIZE | | 1/2 SIZE | | 1/3 SIZE | | 1/4 SIZE | | 1/3 SIZE | |
| TEMPER-ATURE °C | ENERGY FT-LB | FRACTURE % FIBROUS | E | F | E | F | E | F | E | F |
| R.T. | 14.5[†] | 100 | 6.6 | 100 | 4.8 | 100 | 3.5 | 100 | 1.7 | 100 |
| +10 | 14.1 | 100 | 7.3 | 100 | 4.6 | 100 | 3.7 | 100 | 1.8 | 100 |
| 0 | 13.7 | 95 | 7.2[†] | 95 | 4.0 | 95 | 3.4 | 100 | 1.4 | 100 |
| -10 | 13.6 | 80 | 7.4[†] | 90 | 4.2 | 95 | 3.6 | 95 | 1.5 | 100 |
| -20 | 13.0 | 55 | 6.2 | 65 | 4.2 | 90 | 3.6 | 85 | 1.6 | 95 |
| -40 | 12.5[†] | 45 | 5.6 | 40 | 4.3 | 60 | 3.3 | 55 | 1.5 | 85 |
| -60 | 10.2[†] | 30 | 5.6 | 25 | 3.8 | 50 | 2.7 | 45 | 1.4 | 65 |
| -80 | 8.8[‡] | 20 | 4.3[†] | 20 | 3.0 | 30 | 1.9 | 30 | 1.4 | 55 |
| -100 | 7.7[†] | 15 | 3.8 | 15 | 2.3 | 20 | 1.6 | 25 | 1.0 | 45 |
| -125 | 6.1 | 10 | 3.6 | 10 | 1.6 | 15 | 1.5 | 20 | .8 | 25 |
| -150 | 4.2[†] | 5 | 1.8 | 5 | 1.2 | 10 | 1.3 | 15 | .9 | 20 |

*NOTE: Values with greater than 25% deviation from average were discarded.

† Represents one datum point discarded.

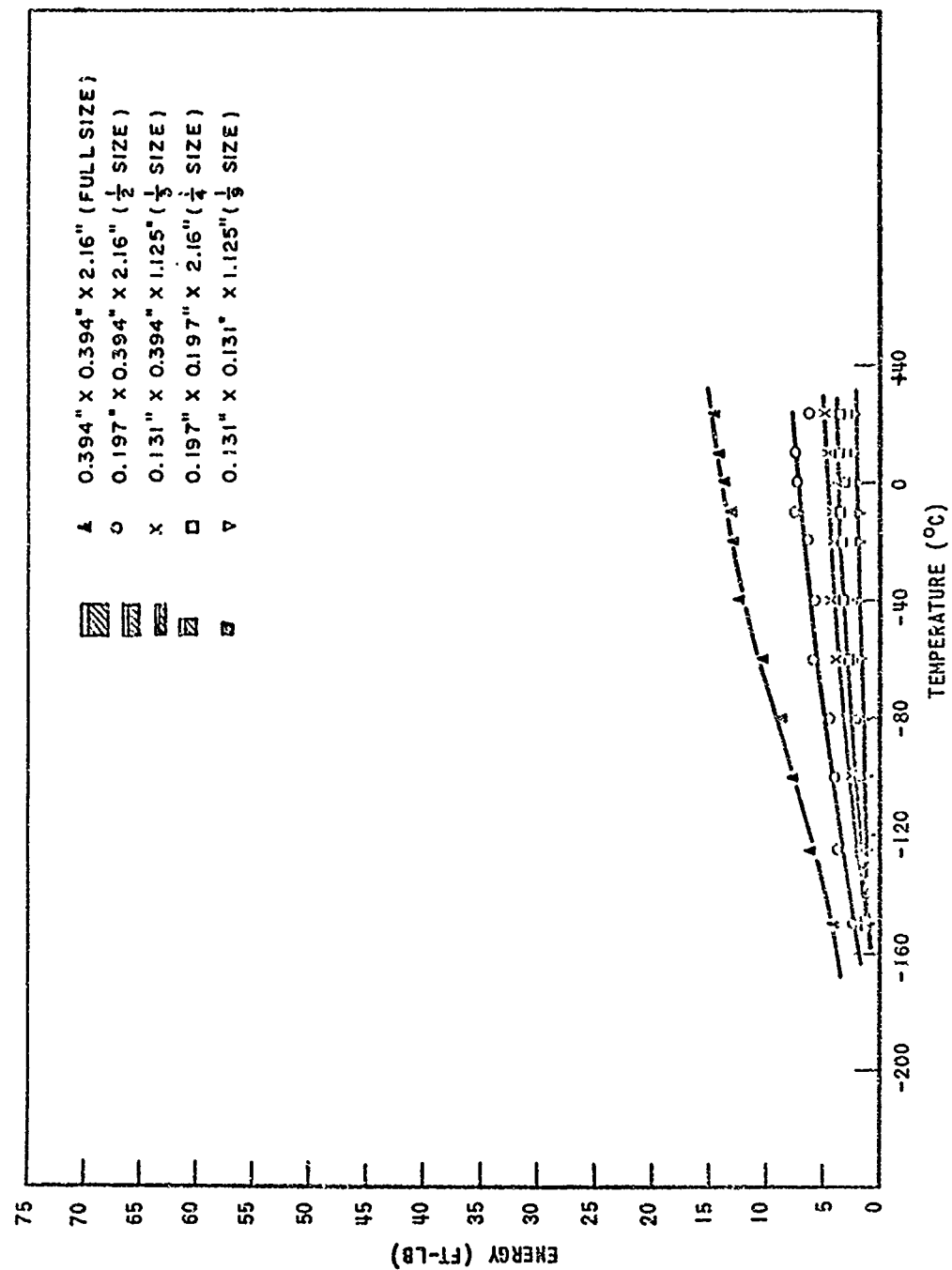‡ Represents two data points discarded.

## TABLE II

| AVERAGED* IMPACT RESULTS OF AISI-4340-HEAT TREAT #1 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | FULL SIZE | | 1/2 SIZE | | 1/3 SIZE | | 1/4 SIZE | | 1/9 SIZE | |
| TEMPER-ATURE °C | ENERGY FT-LB | FRACTURE % FIBROUS | E | F | E | F | E | F | E | F |
| R.T. | 79.5 | 100 | 24.2 | 100 | 13.7 | 100 | 12.9 | 100 | 4.8 | 100 |
| 0 | 75.7 | 100 | 22.7 | 100 | 13.8 | 100 | 12.5 | 100 | 4.3 | 100 |
| -20 | 72.0 | 100 | | | 13.4 | 100 | | | | |
| -40 | 71.3 | 100 | 21.9 | 100 | 13.2 | 100 | 11.4 | 100 | 4.6 | 100 |
| -60 | 60.5 | 95 | 21.1 | 100 | 12.7 | 100 | 11.5 | 100 | | |
| -80 | 53.4 | 95 | 20.8 | 100 | 12.1 | 100 | 10.7 | 100 | 4.6 | 100 |
| -90 | 44.7 | 80 | 20.5 | 100 | | | | | | |
| -100 | 32.5 | 60 | 19.1 | 95 | 10.6 | 100 | 10.1 | 95 | 4.2 | 100 |
| -110 | | | 16.6 | 75 | 10.8 | 90 | | | | |
| -120 | 28.6 | 55 | 12.7 | 50 | 9.2 | 80 | 8.8 | 90 | 4.0† | 100 |
| -135 | | | 10.9 | 45 | 7.4 | 55 | 7.0 | 65 | 3.6 | 95 |
| -150 | 20.4 | 15 | 8.8 | 25 | 6.7 | 45 | 6.7 | 45 | 3.5 | 90 |
| -196 | | | | | | | | | 1.9 | 40 |

*NOTE:  Values with greater than 25% deviation from average were discarded.

† Represents one datum point discarded.

TABLE III

| AVERAGED* IMPACT RESULTS OF AISI-4340-HEAT TREAT #2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | FULL SIZE | | 1/2 SIZE | | 1/3 SIZE | | 1/4 SIZE | | 1/9 SIZE | |
| TEMPER-ATURE °C | ENERGY FT-LB | FRACTURE % FIBROUS | E | F | E | F | E | F | E | F |
| R.T. | 45.8 | 100 | 16.2 | 100 | 8.5 | 100 | 7.9 | 100 | 2.8 | 100 |
| -10 | 43.9 | 100 | | | | | | | 2.8 | 100 |
| -40 | 40.0† | 95 | 15.4 | 100 | 7.9 | 100 | 7.9 | 100 | 2.7 | 100 |
| -50 | | | 14.3 | 100 | | | | | | |
| -60 | 28.6 | 75 | 11.7 | 80 | 7.9 | 100 | 6.6 | 95 | | |
| -80 | 26.7‡ | 60 | 9.3 | 55 | 6.5 | 85 | 5.5 | 70 | 2.5 | 95 |
| -100 | 18.3‡ | 30 | 7.7 | 40 | 5.3 | 55 | 4.8† | 55 | | |
| -120 | 15.6 | 20 | 6.2 | 20 | 4.5 | 40 | 3.8 | 35 | 2.2 | 85 |
| -155 | 14.2 | 10 | 5.9 | 15 | 4.0† | 30 | 3.1 | 20 | 1.4† | 60 |
| -196 | 13.1 | 10 | 5.7 | 10 | 3.6 | 25 | 2.7 | 10 | 0.6† | 15 |

*NOTE: Values with greater than 25% deviation from average were discarded.

† Represents one datum point discarded.

‡ Represents two data points discarded.
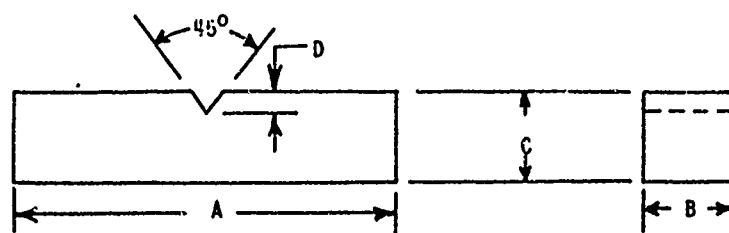
ALL NOTCH RADII = 0.010"

| | DIMENSIONS IN INCHES | | | |
|------|-------|-------|-------|-------|
| SIZE | A | B | C | D |
| FULL | 2.16 | 0.394 | 0.394 | 0.079 |
| 1/2 | 2.16 | 0.394 | 0.197 | 0.039 |
| 1/3 | 1.125 | 0.394 | 0.131 | 0.026 |
| 1/4 | 2.16 | 0.197 | 0.197 | 0.039 |
| 1/9 | 1.125 | 0.131 | 0.131 | 0.026 |

CHARPY V NOTCH SPECIMENS

FIGURE 1
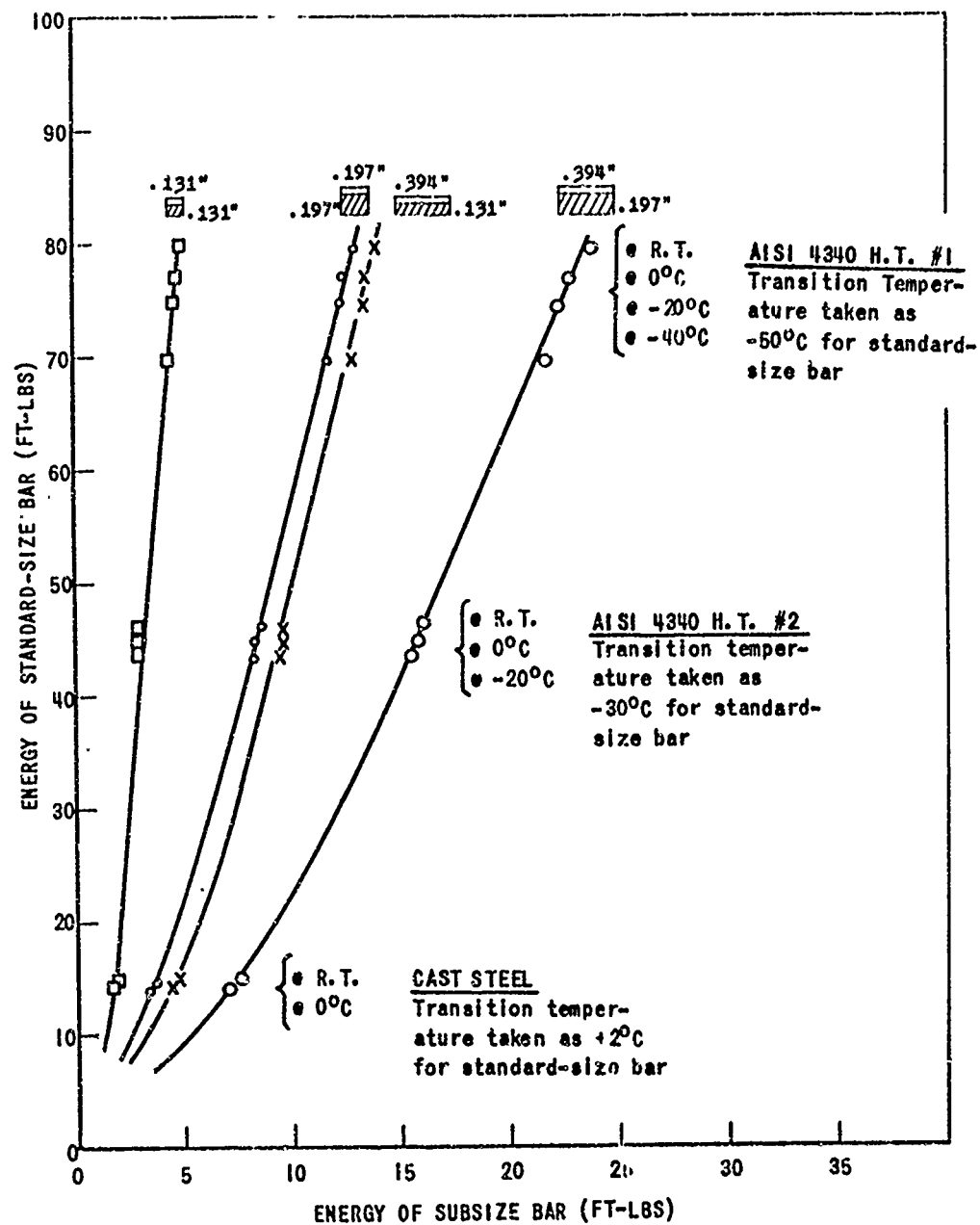
ENERGY VS TEMPERATURE — CHARPY V NOTCH CAST GUN STEEL

Legend:

| | |
|---|---|
| ▲ | 0.394" × 0.394" × 2.16" (FULL SIZE) |
| ○ | 0.197" × 0.394" × 2.16" ($\frac{1}{2}$ SIZE) |
| × | 0.131" × 0.394" × 1.125" ($\frac{1}{5}$ SIZE) |
| □ | 0.197" × 0.197" × 2.16" ($\frac{1}{4}$ SIZE) |
| ▽ | 0.131" × 0.131" × 1.125" ($\frac{1}{9}$ SIZE) |

FIGURE 2

ENERGY VS TEMPERATURE – CHARPY V NOTCH AISI – 4340 HEAT TREAT #1

▲  0.394" x 0.394" x 2.16" (FULL SIZE)
○  0.197" x 0.394" x 2.16" (½ SIZE)
✕  0.131" x 0.394" x 1.125" (⅓ SIZE)
□  0.197" x 0.197" x 2.16" (¼ SIZE)
▽  0.131" x 0.131" x 1.125" (⅙ SIZE)
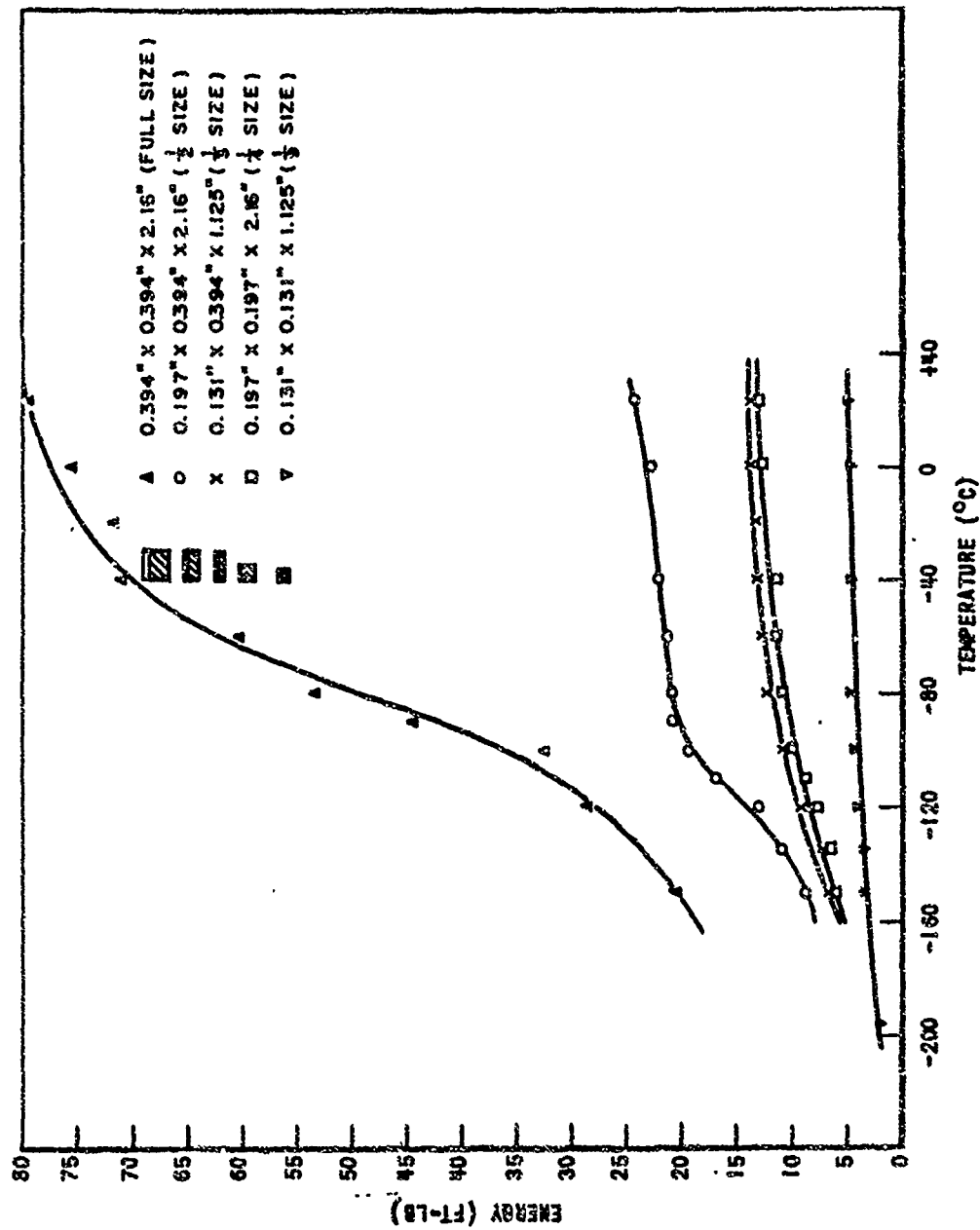
FIGURE 3

ENERGY VS TEMPERATURE - CHARPY V NOTCH AISI-4340 HEAT TREAT #2

Legend:
- ▼ 0.394" X 0.394" X 2.16" (FULL SIZE)
- ○ 0.197" X 0.394" X 2.16" ($\frac{1}{2}$ SIZE)
- × 0.131" X 0.394" X 1.125" ($\frac{1}{3}$ SIZE)
- □ 0.197" X 0.197" X 2.16" ($\frac{1}{4}$ SIZE)
- ▽ 0.131" X 0.131" X 1.125" ($\frac{1}{9}$ SIZE)
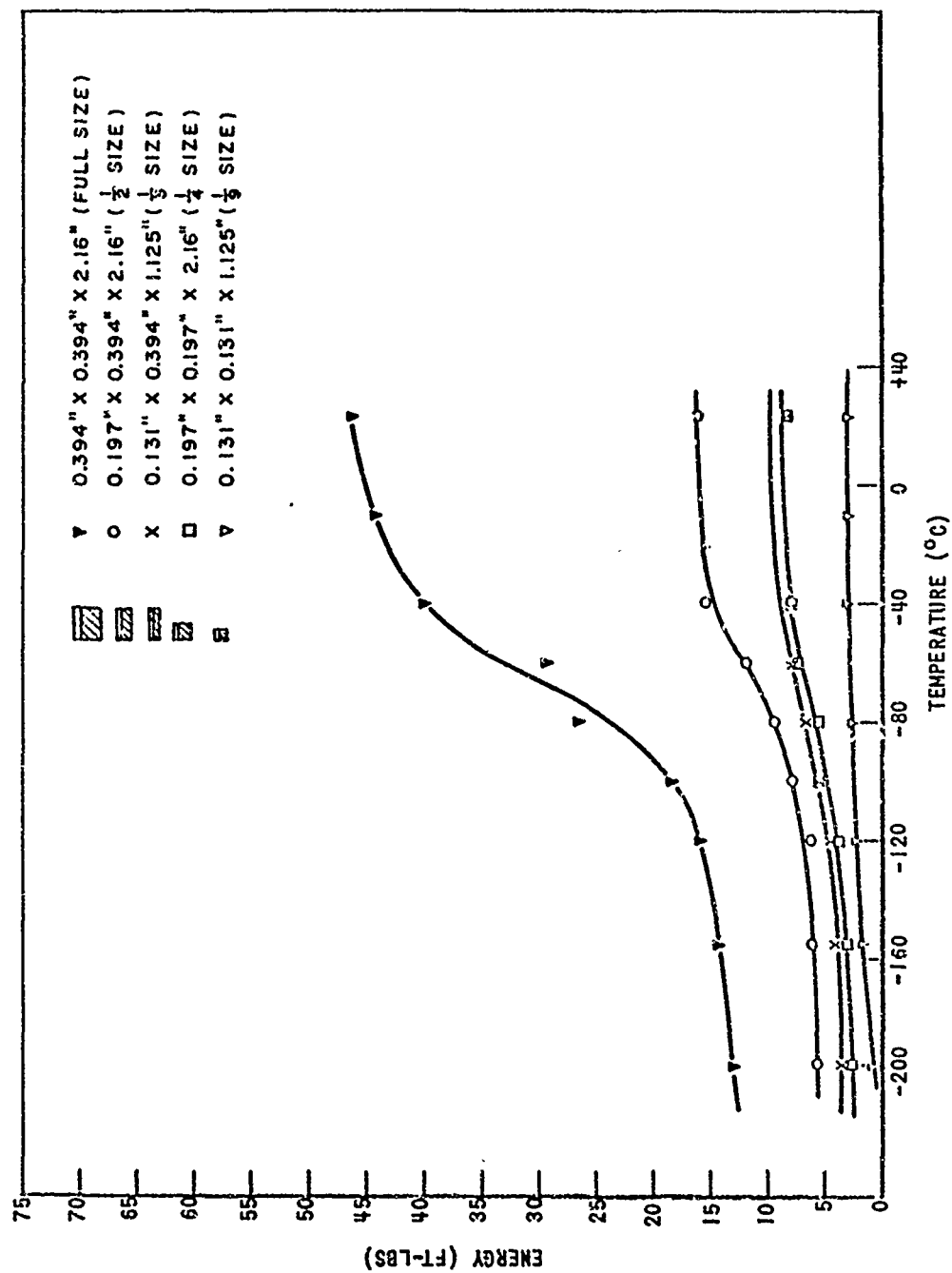
FIGURE 4

CORRELATION CURVES FOR SUBSIZE CHARPY IMPACT SPECIMENS ABOVE
TRANSITION RANGE
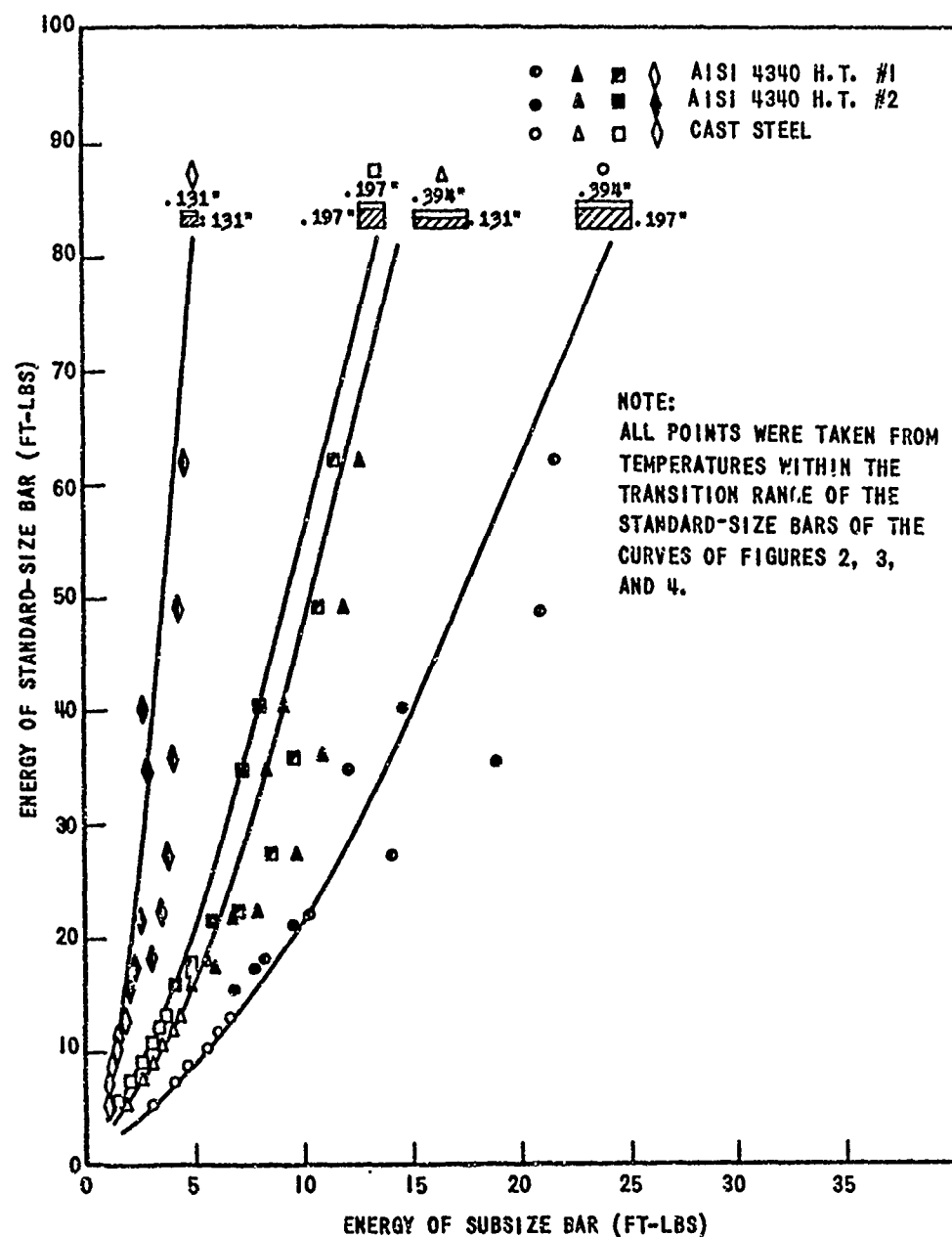
FIGURE 5

EFFECT OF TRANSITION RANGE ON ENERGY VALUES AS PLOTTED ON THE CORRELATION CURVES

FIGURE 6

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Report No. WAL TR 112/91, May 1958, 6 pp - illus -
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